NHDOT SPR2 PROGRAM
RESEARCH PROGRESS REPORT

Project # 26962O	**Report Period:** Year: 2018 ☐Q1 (Jan-Mar) ☒Q2 (Apr-Jun) ☐Q3 (Jul-Sep) ☐Q4 (Oct-Dec)
Project Title: Incorporating Impact of Aging on Cracking Performance of Mixtures during Design	
Project Investigator: Jo Sias Daniel (Co-PI: Eshan Dave) **Phone:** 603-862-3277 **E-mail:** jo.daniel@unh.edu	

Research Start Date:	**Research End Date:**	**Project schedule status:**
December 1, 2016	September 30, 2018	☐ On schedule ☐ Ahead of schedule ☒ Behind schedule

Progress this Quarter (include meetings, installations, equipment purchases, significant progress, etc.):

The work conducted this quarter has focused on the testing and analysis of field cores from Westmoreland project and the 20 hr. PAV binder samples sampled from the 2017 paving projects.

Table 1 below shows the status summary for the project mixture testing. The disc-shaped compact tension (DCT) and semicircular bending (SCB) fracture testing are complete for all the mixtures. The complex modulus and S-VECD fatigue testing for all but the T3 mixture have been completed at the different aging levels.

Table 1- Status Summary for Project Mixtures

Mixture ID	Binder PG Grade	NMAS (mm)	%TRB	Status						
				Received	Aging	Testing/Analysis				
						STOA	95°C@5d	85°C compacted	95°C@12d	135°C@ 24hr.
WM-S-1	PG 58-28	12.5	1.5							
WM-S-2	PG 58-28	12.5	1.0							
WM-S-3	PG 52-34	12.5	1.0							
WM-S-4	PG 52-34	12.5	1.5							
S-1	PG 58-28	9.5	1.0					NA		
T4	PG 64-28	9.5	1.0					NA		
SHS-1	PG 76-28	9.5	1.0					NA		
SHM-1	PG 70-34	12.5	0					NA		
SV-1	PG 64-28	9.5	0					NA		
T3	PG 58-34	12.5	1.0					NA		
T5	PG 64-28	12.5	1.0					NA		

Completed In Progress Not Started

Table 2 below shows the testing that will be conducted on the extracted and recovered binders. The BBR and EBBR tests will be done by NHDOT, and the DSR testing by UNH. The extracted and recovered binders from the four Westmoreland mixtures (WM-S-1, WM-S-2, WM-S-3, WM-S-4) were received by UNH in June. The field cores from these Westmoreland mixtures will be sent to NHDOT for extraction and recovery after testing. Table 3 shows the status summary for the extracted and recovered binder testing. Also, seven binder samples sampled from the 2017 paving projects were received by UNH, and the 4mm DSR testing has been completed for these binder samples and compared with the NHDOT BBR results (the detailed results are presented in the Appendix). Table 4 shows the summary status for the binders sampled during production.

Table 2- Summary Table for Binder Tests

Tests	Virgin Binder (Sampled during production)	STOA	LTOAs	Field Cores
25mm DSR				
8mm DSR				
4mm DSR				
BBR				
EBBR				

Included Not Included

Table 3- Status Summary for Extracted and Recovered Binders

Binder Type	Mixture ID	NMAS (mm)	%TRB	Status					
				Sent to NHDOT for Extraction /Recovery	Extracted Binder received by UNH	Testing/Analysis			
						STOA	95°C@5d	95°C@12d	135°C@ 24hr.
PG 58-28	WM-S-1	12.5	1.5						
PG 58-28	WM-S-2	12.5	1.0						
PG 52-34	WM-S-3	12.5	1.0						
PG 52-34	WM-S-4	12.5	1.5						
PG 58-28	S-1	9.5	1.0						
PG 64-28	T4	9.5	1.0						
PG 76-28	SHS-1	9.5	1.0						
PG 70-34	SHM-1	12.5	0						
PG 64-28	SV-1	9.5	0						
PG 58-34	T3	12.5	1.0						
PG 64-28	T5	12.5	1.0						

Completed In Progress Not Started

Table 4- Summary Table for Production Virgin Binder Samples

Binder Type	Mixture ID	NMAS (mm)	%TRB	Status				
				Sampled Binder Received by UNH	Testing/Analysis			
					Original	RTFO	PAV	
							BBR/8mm DSR	4mm DSR
PG 58-28	WM-S-1	12.5	1.5	NA				NA
PG 58-28	WM-S-2	12.5	1.0	NA				NA
PG 52-34	WM-S-3	12.5	1.0	NA				NA
PG 52-34	WM-S-4	12.5	1.5	NA				NA
PG 58-28	S-1	9.5	1.0					
PG 64-28	T4	9.5	1.0					
PG 76-28	SHS-1	9.5	1.0					
PG 70-34	SHM-1	12.5	0					
PG 64-28	SV-1	9.5	0					
PG 58-34	T3	12.5	1.0					
PG 64-28	T5	12.5	1.0					

Done by NHDOT   Done by UNH   In Progress   Not Started

The complex modulus, S-VECD fatigue and SCB testing are planned to be conducted on the field cores from Westmoreland field sectons. Table 5 below shows the testing status on these field cores. The detailed results are presented in Appendix.

Table 5- Summary Table for Field Cores

Mixture ID	Binder Type	NMAS (mm)	%TRB	Status		
				Testing/Analysis		
				Complex Modulus	S-VECD Fatigue	SCB
WM-S-1	PG 58-28	12.5	1.5			
WM-S-2	PG 58-28	12.5	1.0			
WM-S-3	PG 52-34	12.5	1.0			
WM-S-4	PG 52-34	12.5	1.5			

Completed   In Progress   Not Started

Items needed from NHDOT (i.e., Concurrence, Sub-contract, Assignments, Samples, Testing, etc…):
The detailed mix designs and cross section information for two of the seven 2017 paving projects (shown in Table 6 below) are needed. This information will be used for aging analysis using the model developed in the NCHRP 9-54 project.

Table 6- Summary Table for Project Information Request

Mix ID	Mix Type	Gyration/ Traffic Level	Binder Types	TRB	Project #	Project Name	Roadway	Sample Location
T4	9.5 mm	75	PG 64-28	1.0	16166F	District VI Resurfacing	US 1 (Seabrook) Section ID 17611	Londonderry
T5	12.5 mm	75	PG 64-28	1.0	40871	Statewide	NH 111 (Windham-Salem) Section ID 17503	Hooksett

Anticipated research next 3 months:

In the coming quarter, the research group plans to finish the testing of the available mixtures and the field cores as well as the extracted and recovered binders that are available. UNH will continue to provide NHDOT with selected aged mixtures for extraction and recovery of binder for subsequent testing based on results of tests on the extracted and recovered binders from Westmoreland mixtures. Analysis using the aging model from the NCHRP 9-54 project will continue to compare with measured results from the mixture and binder testing.

Circumstances affecting project: Describe any challenges encountered or anticipated that might affect the completion of the project within the time, scope, and budget, along with recommended solutions to those problems.

The characterization of extracted and recovered binders is behind schedule due to issues that NHDOT has been working through with the extraction and recovery of these materials. As a result of this delay it is anticipated that a project extension will be needed by the researchers.

Tasks (from Work Plan)	**Planned % Complete**	**Actual % Complete**
Literature Review and Testing Plan	**100**	**100**
Laboratory Aging of Mixtures	**100**	**100**
Mixture Material Characterization Testing and Analysis	**90**	**95**
Characterization of Extracted and Recovered Binders and Analysis	**40**	**25**
Development of Screening Tool and Guidelines	**0**	**0**
Reporting	**0**	**0**

Appendix:

Results and Discussion
Linear Viscoelastic Parameters of Field Cores

Complex modulus testing and analysis conducted this quarter on the field cores are presented as the average of three replicates for two mixtures (WM-S-3, 52-34, 12.5mm, 20% RAP; WM-S-4, 52-34, 12.5mm, 30% RAP) in Figures 1 and 2. For both mixtures, there is no significant difference between the dynamic modulus and phase angle of the field cores and the lab aged mixtures (5d@95°C). Based on this preliminary data, the 5d@95°C laboratory aging condition appears to simulate approximately three years of field aging for a surface mixture in NH.

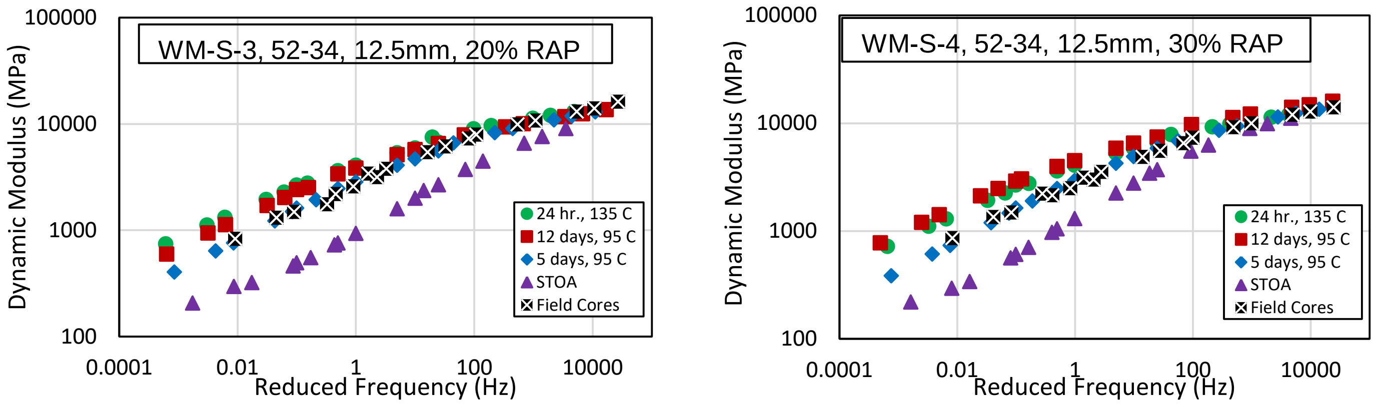

FIGURE 1 Comparison of Dynamic Modulus Master Curves for WM-S-3 Mixture (PG 52-34, 12.5mm, 20% RAP), WM-S-4 Mixture (PG 52-34, 12.5mm, 30% RAP) at Different Aging Levels with Field Cores

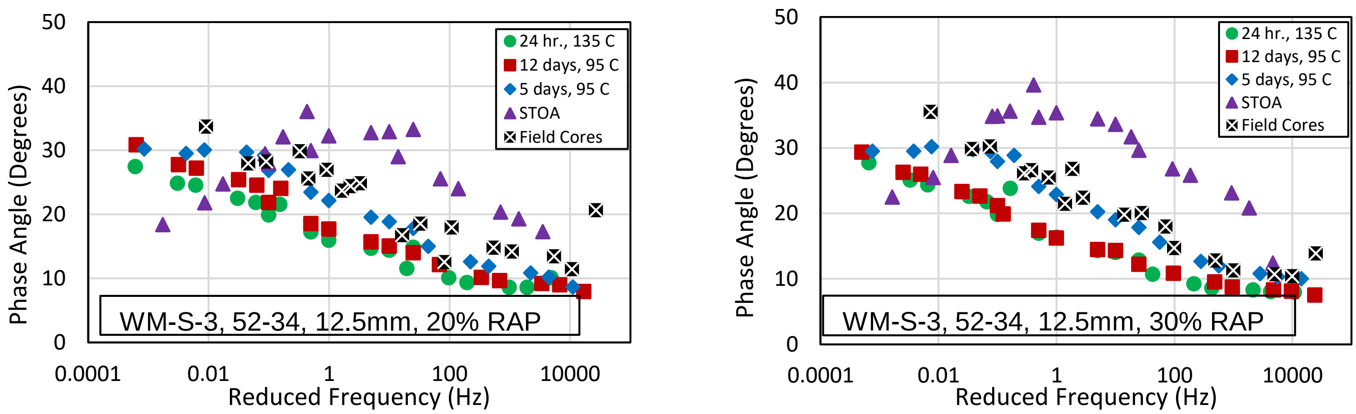

FIGURE 2 Comparison of Phase Angle Master Curves for WM-S-3 Mixture (PG 52-34, 12.5mm, 20% RAP), WM-S-4 Mixture (PG 52-34, 12.5mm, 30% RAP) at Different Aging Levels with Field Cores

Binder Testing Results

The results of 4mm DSR testing (following the MTE method) conducted for the seven 20hr PAV binder samples are presented and discussed in this section.

MTE 4mm DSR Testing

This test method covers the determination of the dynamic shear modulus and phase angle of asphalt binder when tested in dynamic (oscillatory) shear using parallel plate test geometry at low temperature. This test method is intended for determining the low temperature rheological properties of asphlat binder using a Dynammic Shear Rhometer (DSR), which can serve as an alternative to the bending beam rheometer (BBR) and has been proposed for the AASHTO binder test method.

The major point for this method is to conduct the isotherm tests from the coldest to the warmest temperature (-36°C to 40°C, usually in 3 degree increments), and from the highest to the lowest frequencies (15 frequencies from 100 rad/sec to 0.2 rad/sec), by using the appropraite strain level at each combination of test temperature and frequency to get enough data points to constructed the complex shear modulus master curve at certain reference temperature. Then, the complex modulus master curve is converted to the relaxation modulus master curve using Christenson's equation. To determine BBR m-value and creep stiffness $S(t)$ from the mastercurve, Sui et al developed a method to calculate the slope and magnitude of the shear stress relaxation modulus $G(t)$ from the relaxtion modulus master curve at 60 seconds and 10°C warmer than the PG grading temperature, which are correlated with the corresponding $S(t)$ and m-values at 60 seconds and 10°C above the true low PG grading temperature from BBR measurements.

The complex modulus master curve is also used to calculate the R-value and Glover-Rowe parameter.

LTPG (Low Temperature Performance Grading)

Table 7 below shows the BBR test results for the seven tank binder samples from NHDOT. All the binder samples meet the required LTPG based on the BBR results. However, the 58-28 S1, 64-28 T5, 64-28 T4 and 64-28 SV binders don't meet the required LTPG after EBBR conditioning and testing.

Table 7- Summary Table for BBR and EBBR Result from NHDOT

Binder ID	BBR Results			EXTENDED BBR PASS/FAIL
	Stiffness	m-Value	PASS/FAIL	
58-28 S1	205	0.316	Pass	FAIL
58-34 T3	237	0.317	Pass	Pass
64-28 T5	156	0.32	Pass	FAIL
64-28 T4	174	0.316	Pass	FAIL
64-28 SV	182	0.323	Pass	FAIL
70-34 SHM	232	0.322	Pass	Pass
76-28 SHS	193	0.324	Pass	Pass

Figure 3 shows the average LTPG from 3 replicates for each binder sample determined from the 4mm DSR tests. Error bars show one standard deviation. All the binder samples meet the required LTPG, which agrees with the BBR results from NHDOT.

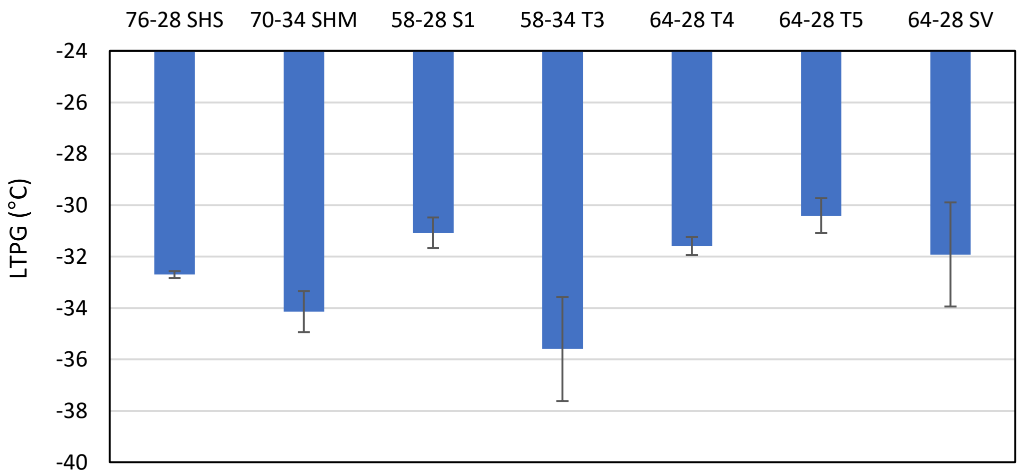

FIGURE 3 LTPG for Different Binder Samples from 4mm DSR Tests

R-value

Figure 4 shows the average R-value from 3 replicates for each binder sample; error bars represent one standard deviation. R-value is the difference between the logarithmic glassy modulus and the logarithmic equilibrium modulus of the binder, simplified as Log (G* @ glassy asymptote) minus Log (G* @ the crossover frequency). As a binder stiffness increases due to aging and oxidation, the R-value increases, resulting in higher cracking susceptibility. As the figure 4 shown, the 70-34 SHM and 76-28 SHS binders show the highest R-value. The other 5 binders show similar R-values.

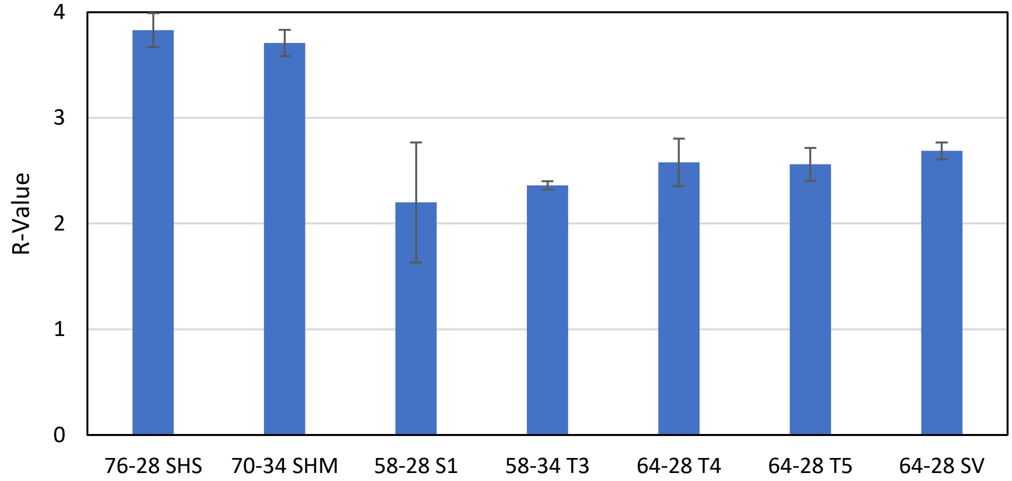

FIGURE 4 R-value for Different Binder Samples from 4mm DSR Tests

ΔTc

ΔTc is defined as the difference between the temperature at which the creep stiffness, *S(t)*, and m-valure criteria from the BBR testing are met. When the ΔTc value is higher than 0, the binder grade is controlled by the stiffness (S-controlled), but when the ΔTc value is lower than 0, the binder becomes m-controlled. S-controlled binders have “extra” relaxation capability and are therefore less prone to cracking. Asphalt Institute suggests using ΔTc = -3.0°C as a crack warning limit and ΔTc = -5.0°C as the cracking limit.

Figure 5 shows the average ΔTc from 3 replicates for each binder sample with error bars showing one standard deviation. The ΔTc values for all of the 7 binder samples are above the crack warning limit. The ΔTc values suggest that 70-34 SHM and 58-34 T3 are the best (of those evaluated) two binders to resist thermal cracking while 58-28 S1 and 64-28 T5 would be the worst.

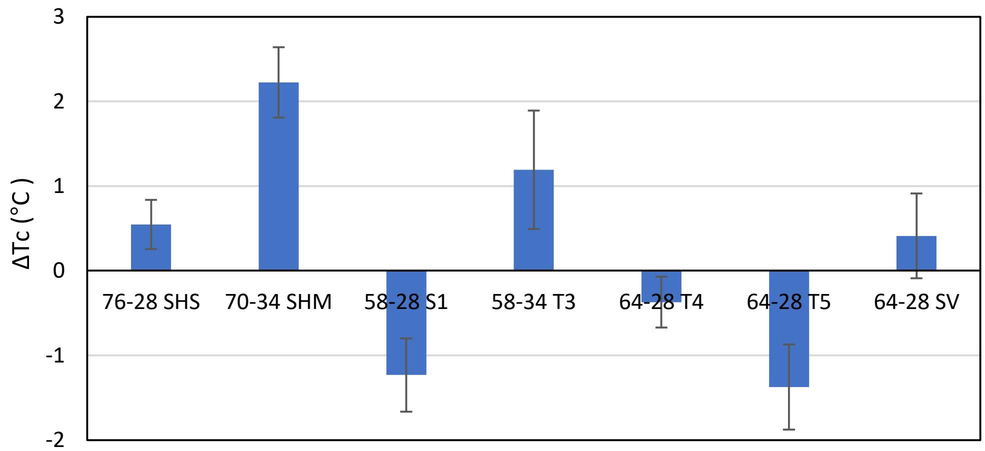

FIGURE 5 ΔTc for Different Binder Samples from 4mm DSR Tests

G-R Parameter

Rowe et al. developed a Glover-Rowe parameter ($\frac{G^*(cos\delta)^2}{sin\delta}$, calculated at 15°C, 0.005rad/sec) to evaluate the cracking susceptibility of asphalt binders. Lower G-R parameter means the binder has the better capability to resist durability cracking. A limiting value of 180kPa is proposed for the onset of cracking, a second value of 450kPa is suggested for the development of the siginificant cracking (block cracking), as the two red lines shown in Figure 6.

Figure 6 also shows the average G-R value from 3 replicates for each binder sample with error bars representing one standard deviation. 70-34 10677 SHM, 58-34 08380 T3 and 64-28 10294 T5 show the lowest G-R values; the other 4 binders show relatively higher G-R values above the cracking onset value but still below the limiting value of the significant cracking (block cracking). Similar to the ΔTc results, 70-34 10677 SHM and 58-34 083380 T3 appear to be the best two binders in terms of resistance to durability cracking.

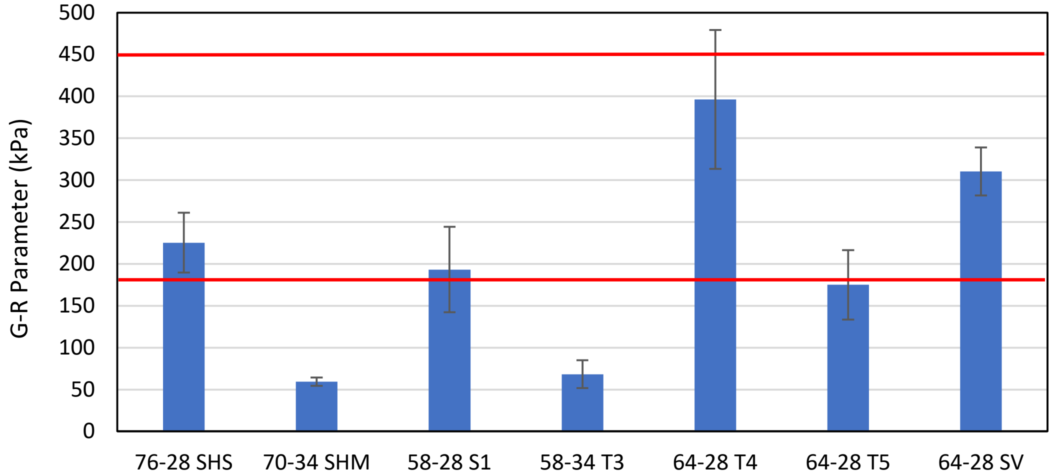

FIGURE 6 G-R Parameter for Different Binder Samples from 4mm DSR Tests